17. ASTRONAUT PERFORMANCE

By WARREN J. NORTH, *Chief, Flight Crew Operations Division, NASA Manned Spacecraft Center*; HELMUT A. KUEHNEL, *Flight Crew Operations Division, NASA Manned Spacecraft Center*; JOHN J. VAN BOCKEL, *Flight Crew Operations Division, NASA Manned Spacecraft Center*; and JEROME B. JONES, *Flight Crew Operations Division, NASA Manned Spacecraft Center*

Summary

21968

As flight experience was gained, confidence in the Mercury mission and particularly in the pilot's capabilities increased, which resulted in the pilot playing an increased role in establishing the configuration and in the operation of the spacecraft. As a result (1) improvements were made in preparing the crews for flight, (2) ground-flight coordination was improved, (3) mission rules became more definite, (4) more functions were delegated to the pilot, (5) many systems modifications were made to increase the pilot's systems management capabilities, (6) operating procedures were simplified, (7) flight activities became more flexible, (8) inflight activity priorities were more clearly defined, and (9) pilot workload became better distributed. The benefits of this experience were manifested during the MA-9 mission where the success of the flight was directly attributable to the performance of the pilot.

Mercury flight experience has shown that man's performance in a spacecraft environment is very similar to his performance in an aircraft environment. This fact will enable manned spacecraft designers to utilize several decades of aircraft design and operational experience in the formulation of man-machine relationships for Gemini and Apollo.

Overall results of the Mercury program verify that the pilot, given adequate controls and displays, and sufficient monitoring instrumentation, is a reliable and flexible system of the entire spacecraft and launch vehicle and enhances the success of the mission. In addition, with the proper equipment, he can greatly benefit the experimental effort.

Introduction

This paper is the summary report on the pilot's ability to operate the Mercury space vehicle and to accomplish experiments as well as make scientific observations. The main topics to be discussed are attitude control of the vehicle and overall management of spacecraft systems because of their importance during Mercury and future space missions, and because it generally in these areas that the most objective and valid data were obtained. The results obtained from each Mercury flight are summarized with particular elaboration upon the MA-9 results since the results of prior flights have been reported in references 1 to 5. Topics are discussed chronologically with examples from each flight when applicable. This approach should illustrate the trend in operational philosophy throughout the program concerning the increased role of the pilot.

Attitude Determination

Throughout the program a great deal of effort was applied toward investigating the relative value of the Mercury spacecraft's controls and displays for various maneuvers and for vehicle orientation. The results of these investigations, as well as brief description of the different controls and displays, are summarized. Figure 17-1 illustrates the display and control systems that were available in the spacecraft.

The attitude displays available in the Mercury spacecraft were a centerline window, a periscope, and an attitude and attitude-rate indicating instrument (fig. 17-1). The centerline window, located directly in front of and almost level with the pilot's head, was trapezoidal

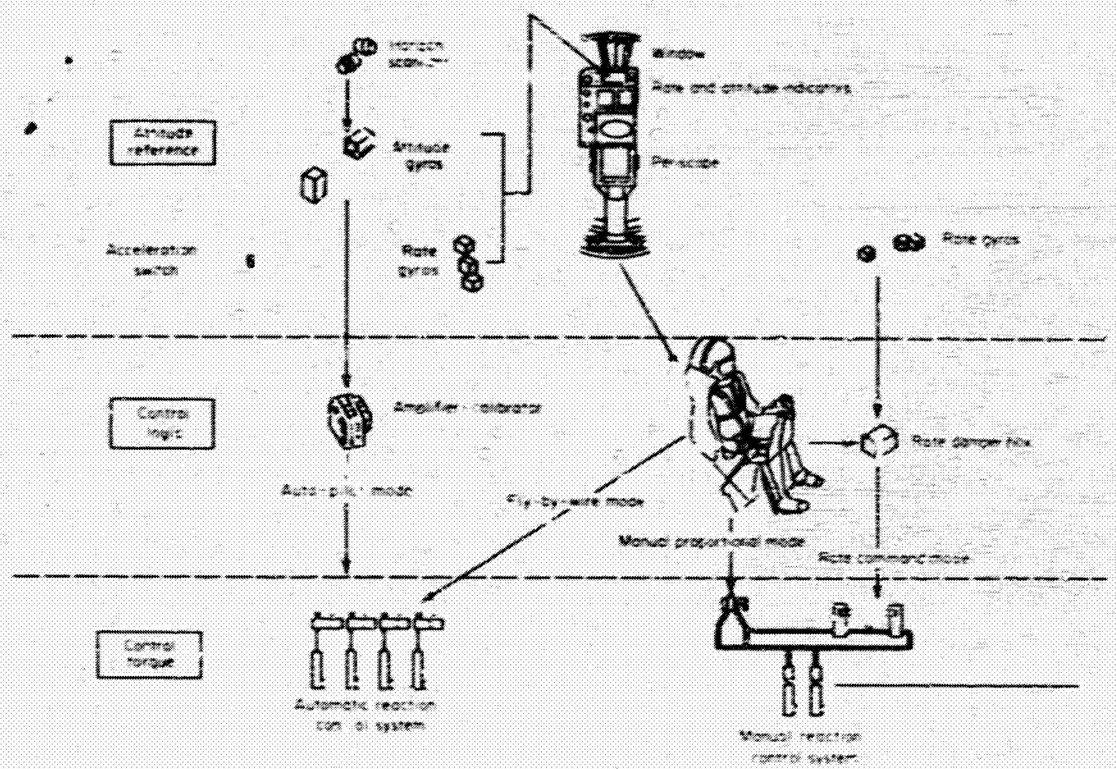


FIGURE 17-1.—Mercury spacecraft display and control systems.

in shape. The viewing limits, with the head restrained, were 33° vertically, 22° laterally at the bottom, and 54° laterally at the top. The periscope, located at the bottom of the center instrument console, was oriented to the earth's nadir when the spacecraft was at a pitch attitude of −14°. The field of view through the periscope was 172°. The attitude and attitude-rate indicating instrument, located at the top of the center instrument console, consisted of six needles, one for each attitude, and one dial which displayed attitude rates. (See fig. 17-2.)

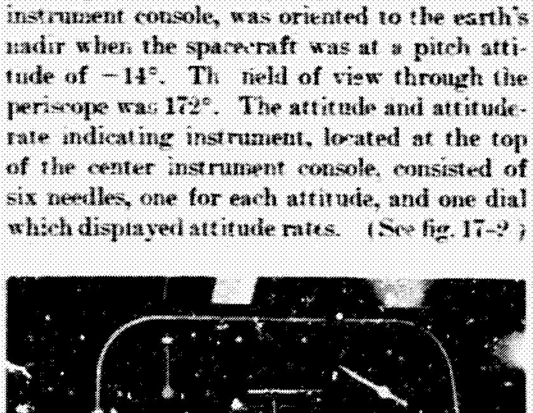


FIGURE 17-2.—Mercury rate and attitude indicators.

The attitude indicators were referenced to the gyros which, in turn, were slaved to the horizon scanners during normal operation.

The relative value of each display system was dependent upon the task to be accomplished. Generally, the window and periscope were both adequate for spacecraft orientation during daylight conditions, whereas only the window was an adequate external display system under reduced lighting conditions. For example, the periscope was the best display for acquisition of the earth horizon and for realinement of the gyros to the true earth-referenced spacecraft attitudes because of its wide field of view. However, in obtaining this wide field of view it was necessary to reduce the image, which resulted in a high attenuation of available light and caused the periscope to be ineffective during the night period. The periscope was removed for the MA-9 flight.

The attitude indicators were used primarily during those periods when the pilot's attention was required in the cockpit, when external references were lacking, and when establishing proper rates and attitudes prior to engaging the

automatic system. The indicators were also preferred for controlling the spacecraft attitude during the firing of the retrorockets because the pilots had been trained much more thoroughly in this method than in using an external visual-display system. Although the attitude indicator system provided good references for such operations as those described above, they also had several shortcomings. Attitude maneuvers beyond a very narrow operating corridor had a great effect upon the accuracy of the system. This problem was reduced as a result of modifications to the later Mercury spacecraft attitude-control systems; however, because of the basic characteristics of the gyros and of the attitude repeater stop limits, it remained a nonversatile system.

In summary, the window was the most versatile and reliable of the three display systems. The periscope disadvantages outweighed its advantages, and the attitude and attitude-rate indicators were a good display system within rather narrow operating limits.

Controls

The Mercury spacecraft had four basic attitude-control modes which could be used singly or in various combinations. These control modes were: automatic stabilization and control system (ASCS), manual proportional (MP), fly-by-wire (FBW), and rate stabilization control system (RSCS). Each of these modes was used and evaluated extensively throughout the early Mercury flights, and as a result, their relative value and efficiency for various attitude-control maneuvers became evident.

The ASCS was capable of controlling spacecraft attitude and rates, or both, in all three axes by using information from the attitude and rate gyros. Four automatic modes of operation were available: a reentry mode, an orientation mode, a retrograde attitude hold mode, and an orbit mode. The reentry mode positioned the spacecraft to the proper reentry attitude, inserted the roll rate, and damped the reentry oscillations. The orientation mode was designed to position the spacecraft to any specifically commanded attitude to within $\pm 1°$. The retrograde attitude hold mode utilized the high torque thrusters to maintain the spacecraft to within $\pm 1°$ and $\pm \frac{1}{2}°$/sec of retrofire attitude. The orbit mode was designed to control the spacecraft at the retrofire attitude to within approximately $\pm 8°$. The purpose of the first three control modes is self-explanatory, and their relative value compared with the manual control system is discussed in a subsequent section of this paper. The orbit mode of operation, however, requires a brief discussion at this point. This mode was designed to control the spacecraft within rather broad limits for long periods of time and with economical fuel usage. While in orbit mode, the pilot could devote his attention to other systems, perform experiments, make observations, or relax. During the MA-9 flight this mode was used extensively for conducting various experiments. In addition, the MA-9 pilot utilized a modified orbit mode of operation by manually positioning the Y-Z plane of the spacecraft parallel to the ecliptic plane and then manually realining the attitude gyros to this new reference plane. This action resulted in automatic control of the spacecraft in the desired plane and allowed the pilot to complete the dim-light photographic experiment, the results of which are reported in paper 12.

Of the three manual control systems, FBW proved to be the most versatile. In the initial design, the 1-pound thrusters were actuated at approximately 25 percent of full control-stick travel, whereas the 24-pound thrusters were actuated at approximately 75 percent of full control-stick travel. In order to prevent inadvertent actuation of the high thrusters, a modification was made on the later spacecraft by which the pilot could, by throwing a switch, lock out the high thrusters. Generally, the pilots preferred this control mode during orbit because precise attitude maneuvers and control, or both, could be accomplished with minimum fuel usage.

The MP system was not used extensively during the Mercury flights except in the MA-9 mission. Earlier mission results indicated that neither fine attitude control nor fuel economy could be obtained with this system during orbit because of the minimum thrust levels that could be obtained and the rather long thrust-response lag characteristics that existed in this system. During the MA-9 mission the pilot demonstrated that by making very rapid hand-controller motions, the MP system would produce thrust impulses of a much lower level than

expected. Results of this mission indicated that the pilot was able to exercise precise attitude control with fuel consumption rates similar to those of the FBW 1-pound thrusters.

The RSCS was used primarily for the reentry phase of the flight. It was normally not used for orbital maneuvers because fine attitude control was difficult to maintain and required an excessive amount of control fuel. The RSCS was removed from the spacecraft for the MA-9 flight.

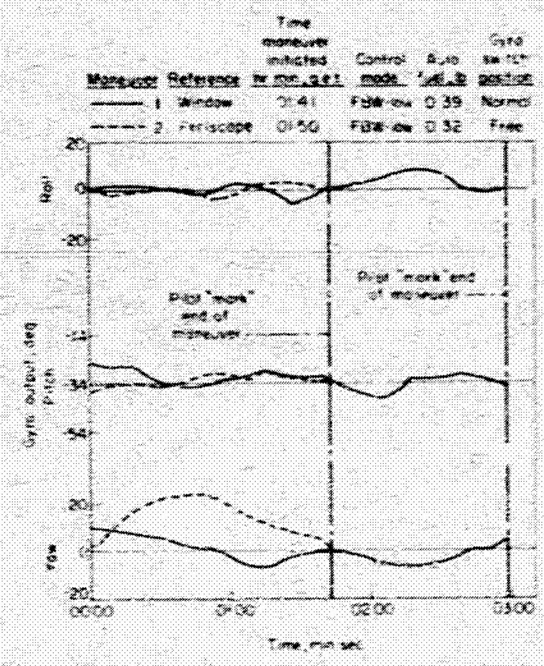
All the various manual control systems were controlled by the pilot by using the three-axis hand controller. This proved to be an adequate controller for manipulation of the manual control systems.

Yaw Determination

Throughout the Mercury program, investigations were made to determine the pilots' abilities to orient the spacecraft in yaw by use of external reference information. Although pitch and roll reference was not considered difficult as long as a view of the earth's horizon was available, as expected, yaw determination was more difficult. Inflight information was considered necessary to evaluate how accurately and how long it would require the pilot to orient the vehicle, particularly when good external references were lacking.

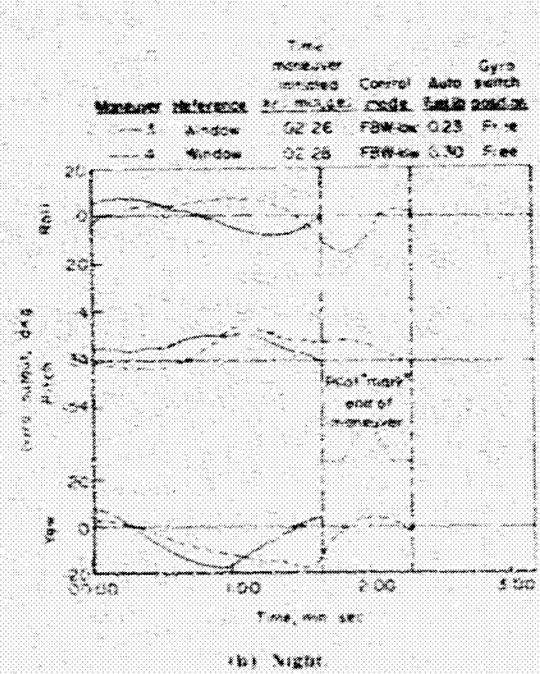
The results from the MA-6 and MA-7 flights indicated that yaw determination during day or moonlit night conditions was not difficult but took more time than did determinations for pitch and roll. Yaw orientation at night with no moon required even more time, and accuracy was somewhat reduced. Both the MA-6 and MA-7 pilots reported that yaw determination by using the window was improved as the vehicle was pitched toward the nadir point. However, since the horizon is not in view to the pilot beyond a pitch-down attitude of approximately 45°, this method makes it difficult to distinguish between yaw and roll errors.

The results of the first two orbital flights suggested that a thorough analysis of yaw determination areas was desirable. A series of yaw maneuvers were planned and accomplished during the MA-8 mission which provided quantitative information on the use of the window and periscope as independent references for determining yaw during both day and night phases of the orbit. (See ref. 5.) The results of these maneuvers are shown in figures 17-3(a) and 17-3(b) and include the attitude variation in all three axes, fuel, time required, and the sole



(a) Day.

Figure 17-3.—Yaw maneuvers during MA-8 mission.



(b) Night.

Figure 17-3.—Concluded.

reference used. At the termination of each maneuver the pilot "marked" it on the onboard tape recorder.

As can be seen by these figures, the pilot was successful in determining yaw under both day and moonlit night conditions by using the view through the window as a sole reference. Furthermore, these maneuvers were accomplished at a pitch attitude of $-34°$, which made the horizon available for good pitch and roll reference. The day yaw maneuver in which the view through the periscope was used was completed within the same accuracy and time period as were the yaw maneuvers in which the view through the window was used. The pilot did not attempt a night yaw maneuver using the periscope because he found that it was ineffective even under moonlit night conditions. The pilot stated that he could have alined the spacecraft much more quickly than these maneuvers indicated if urgency had been a more important consideration than the conservation of fuel.

Since the information obtained from the first three orbital missions was quite conclusive, the periscope was removed from the MA-9 spacecraft, and no specific investigation concerning yaw determination was planned for the MA-9 flight. However, it should be noted that in preparing for retrofire, the MA-9 pilot performed a very critical and precise yaw alinement at night by using stars and ground references only.

The MA-9 pilot reported that yaw determination in daylight was quite easy even when only a small portion of the earth horizon was in view ($-20°$ to $-25°$, pitch attitude). He felt he could accurately aline the spacecraft directly toward or away from the direction of motion over the ground within 1°. At the 90° yaw position he believed his accuracy might be degraded to $\pm 10°$. The pilot used several cues to determine yaw attitudes and rates during daylight, such as the "streaming by" of terrain features, and cloud patterns, or both, the convergence point of these flow lines, and the tracking of terrestrial objects or cloud prominences across the window.

The pilot reported that yaw attitude determination at night was not difficult but it usually required more time. If he was well dark adapted and the moon was illuminating the earth, he used the motion of terrestrial features and cloud features. Occasionally, lighted cities provided good yaw reference even without moonlight. When these references were not available, he was required to use identifiable stars and constellations. This was more complicated and usually took more time because the restricted field of view through the spacecraft window made identification of the constellations more difficult.

A convenient method of yaw determination was noted by the MA-9 pilot after observing the relative motion of the so-called fireflies seen by all of the pilots of previous orbital missions. These luminous particles, which appeared to emanate from the thrusters, were observed to move outward from the spacecraft and then to recede back along the spacecraft's trajectory in the manner of a contrail, remaining visible for several seconds. The pilot believed that by positioning the spacecraft relative to the motion of these particles, an accurate determination of the 0° yaw position could be achieved.

Gyro Realinement

The realinement of the attitude gyros to the spacecraft's attitude was an important function because it directly affected the usability of the entire ASCS and Mercury attitude indicating systems. The two important objectives in accomplishing this maneuver were maximum accuracy of alinement and minimum fuel expenditure. There were several variables which directly affected these objectives, such as the control and display systems used, the external conditions (day-night), the external references available, and the time available. Time was particularly important because the spacecraft could be alined accurately and with low fuel usage even during worst conditions, providing ample time was available to complete the maneuver.

One important systems modification which significantly affected the capability and ease of realining the gyros to the spacecraft attitude was changing the gyro caging position to $-34°$ in pitch. All but the MA-9 spacecraft's gyros caged to the zero position in all three axes. With the spacecraft in this position, the earth horizon was not available through the window. Although the total realinement maneuver was quite complex in the earlier missions, the MA-9 realinement maneuver was relatively simple and

consisted of orienting the spacecraft to the retroattitude position by using the horizon and caging and uncaging the gyros (fig. 17-4). As an example, the amount of fuel used by the MA-9 pilot in accomplishing this maneuver was only approximately 25 percent of the average amount required for the maneuver during the previous Mercury missions.

FIGURE 17-4.—Horizon view at retroattitude.

Attitude Control

Turnaround Maneuvers

During the suborbital flights and the first oribital flight the spacecraft was turned around to the retroattitude position by the ASCS, whereas the turnaround maneuvers after orbital insertion for the subsequent orbital missions were accomplished manually as shown in table 17-I. The reasons behind this change warrant a brief discussion.

Table 17-I.—Summary of Turnaround Maneuvers

Flight	Control system	Fuel, lb	Time, min:sec
MR-3	ASCS	4.0	0:30
MR-4	ASCS	4.0	0:35
MA-6	ASCS	5.8	0:38
MA-7	FBW (high and low)	1.6	0:30
MA-8	FBW-low	0.3	1:10
MA-9	FBW-low	0.2	1:40

ASCS—Automatic stabilization and control system.
FBW—Fly-by-wire.

At the very beginning of Mercury Project, it was not known how well the pilot would be able to function in a space environment. This contributed to the Mercury spacecraft being designed so that most of the inflight functions would be automatic with the man being used as a backup system. As flight experience was gained, confidence was increased in the spacecraft, mission operations, and particularly in the man's capabilities. As a result the pilot was permitted more latitude and given more responsibilities as far as inflight activities, such as the turnaround maneuver, were concerned. A second important factor was that fuel conservation became more important during the longer duration missions. Early flight results indicated that an automatic turnaround maneuver would require between 4 and 6 pounds of control fuel. Results on the Mercury procedures trainers, which simulated quite accurately fuel usages for the various control modes, indicated that the pilot could, after practice, perform the maneuver within the same time period required by the ASCS and with a significant savings in fuel.

On this basis, it was decided that the MA-7 pilot would perform the turnaround maneuver, by using FBW, and complete it within approximately the same time normally required by the ASCS. As can be seen by table 17-I, the MA-7 turnaround required only 1.6 pounds of fuel as compared with the 5.8 pounds of fuel required for the MA-6 automatic turnaround. This fuel conservation verified that subsequent flight turnarounds should be conducted manually.

During the MA-8 flight it was planned that if the flight were proceeding smoothly, the turnaround maneuver would be executed at a leisurely pace at a yaw rate of 3°/sec to [illegible]°/sec with the pilot relying solely on the rate and attitude indicators and using only the FBW 1-pound thrusters to conserve fuel. A secondary objective was to confirm that the pilot could perform the maneuver as precisely in a space-flight environment as he could in trainers on the ground.

The pilot performed the maneuver identically as it had been practiced on the procedures trainer. Figure 17-5 shows the flight gyro attitudes with a background envelope of five turnaround maneuvers accomplished on the

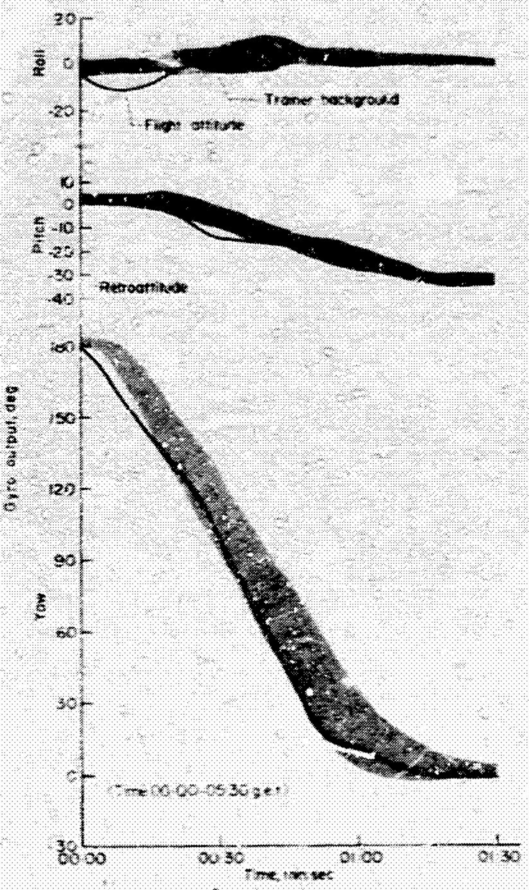


FIGURE 17-5.—Turnaround maneuver, MA-8 mission.

procedures trainers. The pilot executed the maneuver smoothly and with precision, using 0.3 pound of control fuel, which is less than 10 percent of the control fuel normally required by ASCS. As a result of this flight it was clearly established that a leisurely executed manual turnaround, providing the flight was proceeding smoothly, was the most efficient maneuver.

The MA-9 pilot accomplished the turnaround maneuver in a manner similar to that of the MA-8 pilot except that it was not intended to be completed in as precise a fashion as the MA-8 maneuver. He used FBW-low to conserve fuel, but he elected to observe and photograph the launch vehicle rather than position the vehicle directly to the proper retroattitude position. The pilot had been informed that he had a good insertion, that all systems were functioning properly, and therefore that it was not imperative for the spacecraft to be pitched down to retroattitude. The MA-9 turnaround maneuver required only 0.2 pound of control fuel.

Retrofire

Control of the spacecraft attitude during the firing of the retrorockets was perhaps the most critical and exacting function of either the pilot or the ASCS. Therefore, a great deal of the astronaut's attitude control training on the various fixed and dynamic trainers was devoted to the determination of the relative value of the different control-display configurations and in perfecting the pilot's capability to use these various configurations effectively in accomplishing this maneuver.

The summary of the planned and actual control-display systems used for controlling the spacecraft during the retrofire maneuver of the manned Mercury flights and resultant fuel usages is shown in table 17-II. Of particular note is the fact that only one (MA-8) of the four orbital flight retrofire events was accomplished as planned. The amount of fuel used agrees quite well with the trainer results; that is, in terms of fuel savings there are no significant advantages in selecting any particular control mode.

During the orbital flights it was planned to use the ASCS to control the spacecraft during the retrofire event because it was designed to maintain attitude within very tight limits of ±1° and because a manual retrofire did not represent a significant saving in fuel. However, because of systems failures or anomalies affecting the ASCS only the retrofire maneuver of the third orbital flight (MA-8) was accomplished solely by the ASCS.

The MA-6 pilot decided to backup the ASCS by using the MP control system. With this particular set of control modes 11.6 pounds of control fuel were used during the maneuver.

Because of a problem with the ASCS, the MA-7 pilot controlled the spacecraft during retrofire by using both FBW and MP, again resulting in a rather high fuel usage. Because of an error in the pitch indicator the pilot was required to cross-check between the view out the window and his instruments.

The MA-8 spacecraft was controlled by the ASCS during the retrofire event within ±1° in

Table 17-II.—Summary of Retrofire Maneuvers

Flight	Control system		Display	Fuel, lb	Landing error, nautical miles
	Planned	Actual			
MR-3	MP	MP	Instruments	4.	
MR-4	MP	MP	Instruments	3.6	
MA-6	ASCS	[1] ASCS, MP	Instruments	11.6	−40
MA-7	ASCS	[1] FBW, MP	Instruments and window	7.0	+250
MA-8	ASCS	ASCS		3.8	−4
MA-9	ASCS	MP	Instruments and window	3.2	−1

[1] Double authority
MP—Manual proportional
ASCS—Automatic stabilization and control system
FBW—Fly-by-wire

all axes. The pilot had selected MP as a backup but it was not required.

As a result of the loss of ASCS power, the MA-9 pilot was required to initiate the retrofire event manually and to control the spacecraft during retrofire by using the rate gyro indicators (the attitude indicators were non-operational) and the view of the earth through the window as rate and attitude references, respectively. The pilot, realizing that he would be conducting the retrofire maneuver shortly after sunrise of the final daylight phase, oriented and maintained the spacecraft very close to the proper retroattitude throughout the last night period by using stars and clouds as references. The pilot was well prepared for retrofire, having completed well in advance the storage and preretrosequence checklists.

During the retrofire maneuver, the pilot used MP and cross-checked between his rate indicators and the view through the window. Because of a high contrast between the relative brightness of his interior and exterior references, the pilot experienced difficulty in adapting his vision while shifting from one reference to the other. Consequently, he had to shade his eyes with his left hand when attempting to view his rate indicators. In spite of this problem and the fact that he did not have the opportunity to practice retrofire maneuvers with this combination of attitude references, except much earlier in his training program on the air-lubricated free-attitude (ALFA) trainer, the pilot was able to maintain excellent control of his spacecraft with this combination of attitude references, as evidenced by the nominal reentry trajectory and accuracy in landing position.

Figure 17-6 shows the spacecraft's attitude rates and attitudes, which were calculated from an integration of the spacecraft rates during the retrofire period. The calculated attitudes and the initial attitude of the spacecraft at the

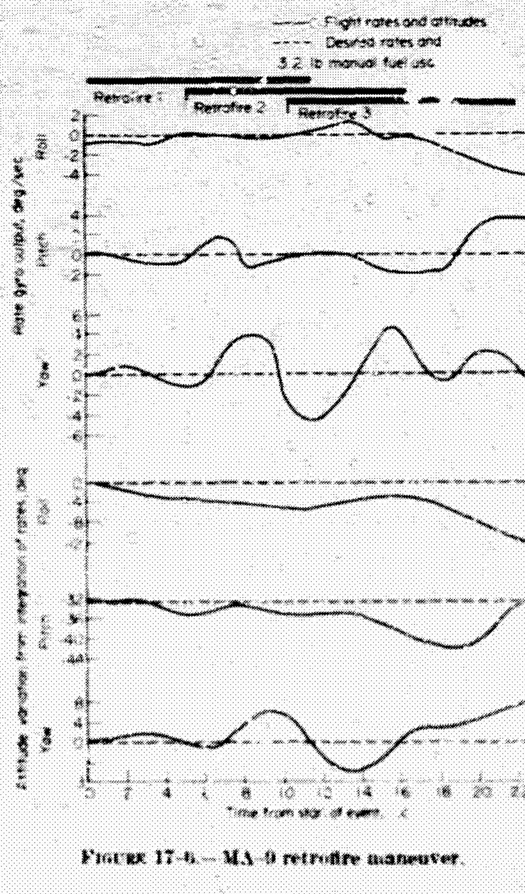


Figure 17-6.—MA-9 retrofire maneuver.

beginning of the retrofire were further verified by reentry trajectory computations. The pilot controlled rates extremely well particularly in pitch which is the most critical axis. Rate control was maintained within ±2°/sec in pitch and roll and within ±5°/sec in yaw throughout the first 19 seconds of the 22-second retrofire period. A maximum misalinement torque of approximately 40 to 50 foot-pounds appears to have occurred in left yaw when the number two retrorocket fired. This value represents approximately 40 percent of the MP control capability.

The pilot maintained good control of spacecraft attitudes, with a maximum deviation of −12° in roll at the completion of the maneuver. Deviations in pitch and yaw attitude were negligible as far as the reentry trajectory and landing accuracy are concerned. The maximum pitch deviation was 9°, which occurred very late in the retrofire period; and the maximum yaw attitude deviation was 5°. The pilot purposely maintained the pitch attitude at the nominal −32° position or slightly lower, a direction of deviation which least affects the reentry trajectory.

Reentry

During the reentry the ASCS or the pilot, by means of one of the manual control modes, was required to initiate and maintain a roll rate of approximately 10°/sec and to damp the oscillations in the pitch and yaw axes. Since the frequency and damping of the oscillations varies considerably during the reentry phase, with frequency increasing until maximum dynamic pressure, and damping decreasing after the maximum dynamic-pressure period, the control task requires a considerable amount of pilot skill and technique.

The preferred control systems for this task were either the auxiliary damping (ASCS) or the rate command mode. Rate command, although highly effective in controlling the oscillations, usually consumed a large amount of fuel, as can be seen in the case of the MA-8 reentry shown in table 17-III. The MP control mode had a significant response lag and tail-off in thrust, which made it very difficult to damp effectively. The FBW was not completely adequate for effective control because it was limited to the selection of two discrete thrust levels.

All of the manned Mercury flight reentries except MR-3 were planned to be controlled by the auxiliary damping or rate command control modes. Furthermore, these two control modes were used entirely or in part for each Mercury flight reentry with the exception of the MA-9 reentry. The rate command system had been removed from the MA-9 spacecraft and the auxiliary damping system was inoperative because of the loss of ASCS power.

The MA-9 pilot decided to control the reentry by using FBW, but when he checked the system just prior to 0.05g, he was not satisfied with the way it was operating and elected to use both MP and FBW. During the early portion of the reentry he was able to damp the small and rather slow oscillations by using the FBW 1-pound thrusters and the MP control

Table 17-III.—Reentry Control

Mission	Control mode		Fuel, lb
	Planned	Actual	
MR-3	MP	MP, switched to Aux. damp.	6.5
MR-4	RSCS	RSCS	6.0
MA-6	Aux. damp.	(MP and FBW)[1] switched to Aux. damp.	8.6
MA-7	Aux. damp.	Aux. damp.	4.6 to fuel depletion
MA-8	RSCS	RSCS	10.0
MA-9	Aux. damp.	(FBW and MP)[1]	5.2

[1] Dual authority
MP—Manual proportional
RSCS—Rate stabilization and command system
Aux. damp.—Auxiliary damping part of automatic (ASCS) system
FBW—Fly-by-wire

mode. At approximately 1 minute and 30 seconds prior to peak reentry deceleration, the pilot inadvertently actuated the FBW-high yaw thruster. This actuation resulted in almost 49 pounds of control thrust and added to the amplitude of the oscillations. However, the pilot maintained positive control of the oscillations through drogue parachute deployment. The pilot had no other difficulties in controlling the reentry oscillations except during maximum deceleration for a brief period in which he was unable to manipulate the control handle properly because the g-forces pulled his arm away from the control handle and into a trough on the arm rest.

The maximum frequency of oscillations occurred at peak deceleration with a period on the order of 0.9 second. Maximum rates were approximately $\pm 15^\circ$/sec with a maximum amplitude of approximately $\pm 10^\circ$ in pitch and yaw which occurred after peak deceleration. The pilot reported that he believed he needed full-authority control to be effective after the peak deceleration point.

Systems Management

As flight experience was gained and as the successive flights increased in length and complexity, it was necessary to make many modifications and improvements in the controls, displays, and monitoring instrumentation so that the pilot could more effectively manage and assess the status of the spacecraft systems. Increased onboard monitoring capability was particularly important during the MA-9 flight because of the long time periods during which the spacecraft was not within communication contact with the various ground stations. A second advantage of onboard monitoring instrumentation was that it was often more reliable than telemetered data, and, if discrepancies did occur between ground and flight information, the actual status could be better determined with the onboard instrumentation. Finally, as mission duration increased the management of consumables, such as fuel and electrical power, became more critical.

Figure 17-7, which compares the MR-3 and MA-9 spacecraft instrument panels, illustrates the numerous changes in the Mercury panel configuration. These changes primarily resulted from the increased knowledge about the spacecraft systems and their operations as well as the mission requirements. One of the major modifications was to the attitude control system and its controls in order to maximize the capabilities of the system and also to simplify the control system management requirement.

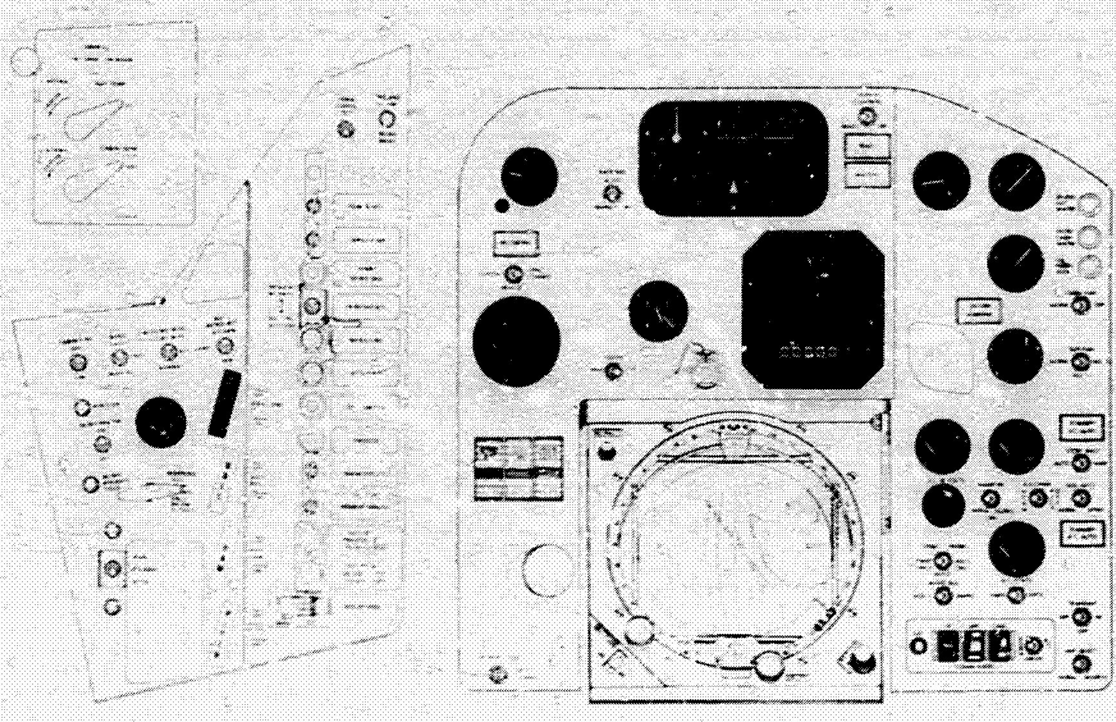
Control-Mode Switching

A major pilot function during all of the Mercury missions, but particularly during the MA-9 flight, was control-mode usage and switching which had a direct effect upon control-fuel expenditure and the success of the entire mission. Table 17-IV shows control-mode usage and switching during the MA-9 flight. In general, the control system was used almost exactly as planned until the 0.05g relay prematurely latched in and the ASCS power was subsequently lost. After this point, the pilot used FBW and MP, or both, since these were the only available systems.

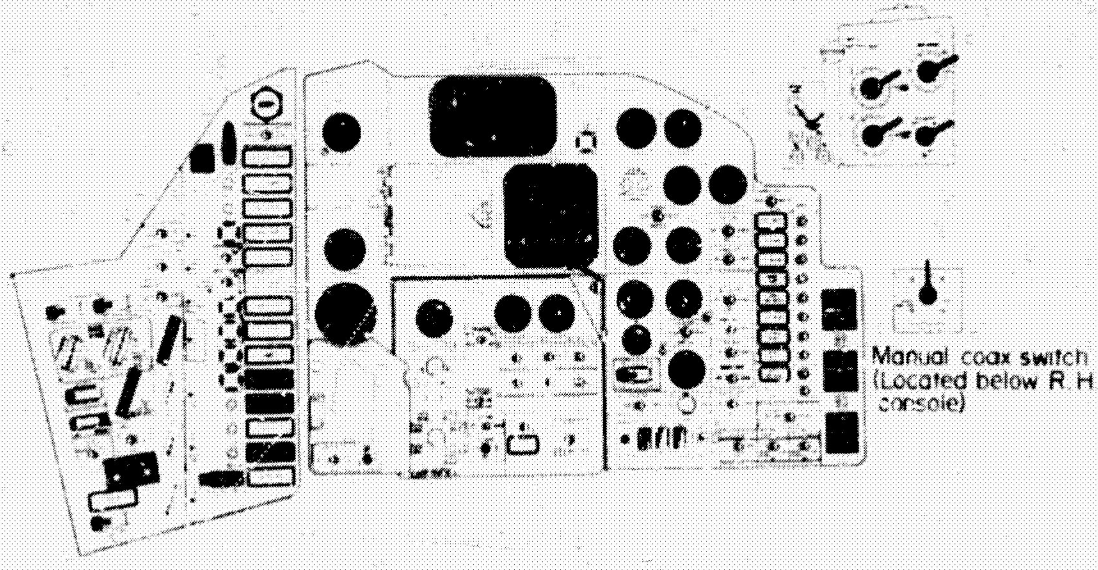
The pilot was very successful in switching from the manual control modes to the ASCS. The orientation high-thruster mode was never

Table 17-IV.—MA-9 Control Mode Usage

Control mode configuration	Percentage time used in rank order	Maximum time used at any one time hr:min	Frequency used
Drift	43	13:[illegible]	2
Drift and MP	26	8:[illegible]	1
ASCS orbit	13	1:20	7
Drift and FBW-low	13	3:11	1
FBW-low (gyros uncaged)	2	0:11	8
ASCS reentry	2	0:37	1
MP (gyros uncaged)	1	0:04	5



(a) MR-3 configuration.



(b) MA-9 configuration.

FIGURE 17-7.—Spacecraft instrument panels.

inadvertently actuated throughout the entire flight. The maximum excursions, during the eight times the spacecraft was manually alined to retroattitude and control switched over to the ASCS, were 5° in attitude and ±½°/sec in rate. The pilot did not at any time inadvertently use double authority during the mission. Double authority was used purposely for the reentry.

The MA-9 pilot's success in control mode utilization can be attributed primarily to two areas: simplification of the control mode switching operations, which reduced the chances of inadvertent use of orientation mode or inadvertent dual authority, and a very thorough understanding of the operational characteristics of the entire attitude-control system.

Pilot Reliability

Throughout the Mercury flights there were several minor and a few major systems failures. In order to illustrate the value of the pilot as a backup and/or primary system indispensable to the Mercury space flights, a brief review of the failures which occurred in the spacecraft's attitude-control system during the four orbital flights and the effect that these failures would have had on mission success had the spacecraft been unmanned is warranted.

At approximately 1 hour 30 minutes after lift-off of the MA-6 flight, the 1-pound left yaw thruster malfunctioned. After repeated switching between the ASCS and FBW control modes, the thruster began to function properly. However, almost immediately thereafter the right yaw 1-pound thruster malfunctioned and continued to be inoperable for the rest of the flight. Although mission safety was not jeopardized, this malfunction would have required an early termination of the flight because, had the pilot not been on board, the spacecraft would have repeatedly dropped into the ASCS orientation high-thruster mode, and a premature fuel depletion would have resulted.

The pitch horizon scanner malfunctioned throughout the MA-7 flight. At retrofire, the pitch horizon scanner read approximately −16°, whereas trajectory computations based on radar tracking data yielded a pitch attitude of −36.5°. This discrepancy was verified by the pilot who reported that the ASCS orientation mode caused the vehicle to pitch down below the −34° position to such an extent that the earth's horizon was no longer visible through the window. As a result the pilot had to place the attitude permission switch to the "bypass" position and initiate and control the retrofire event manually. Without the pilot the retrofire could not have been initiated from the proper attitude.

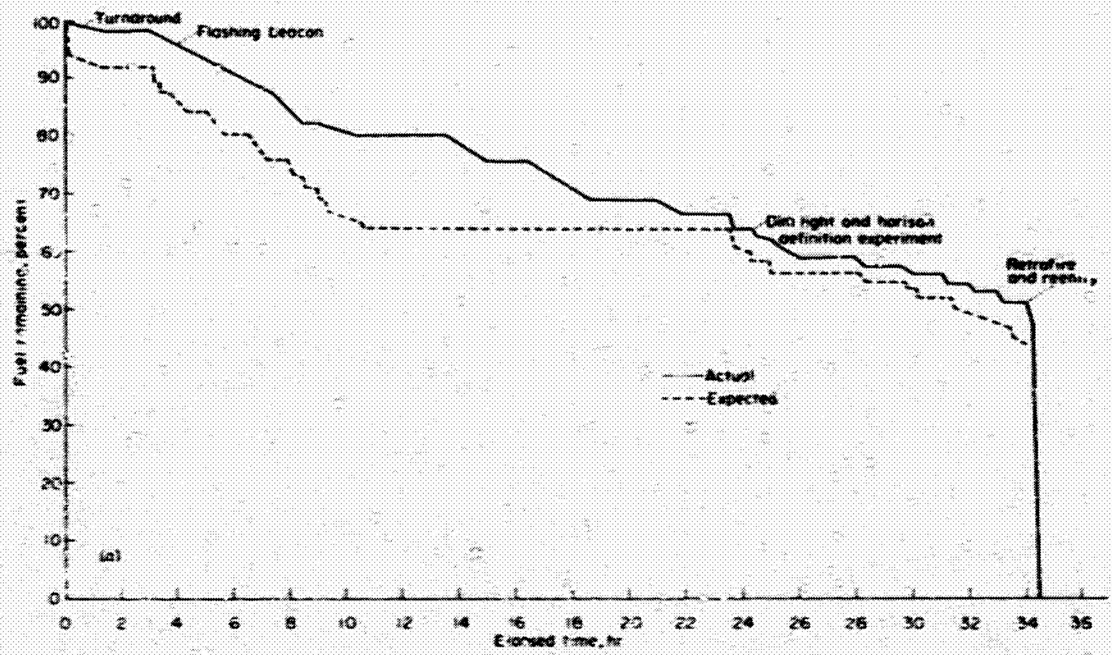
During the MA-9 flight, the amplifier calibrator locked into the 0.05g configuration, which resulted in putting the ASCS into the reentry mode of operation. Shortly thereafter, all ASCS power was lost, and the pilot was required to perform manually all subsequent functions, such as retrofire initiation, retrofire attitude control, and damping of reentry rate oscillations.

In summary, without the man, only the MA-8 flight would have progressed normally; the MA-6 mission would have had to be terminated early; and the MA-9 spacecraft would not have reentered successfully.

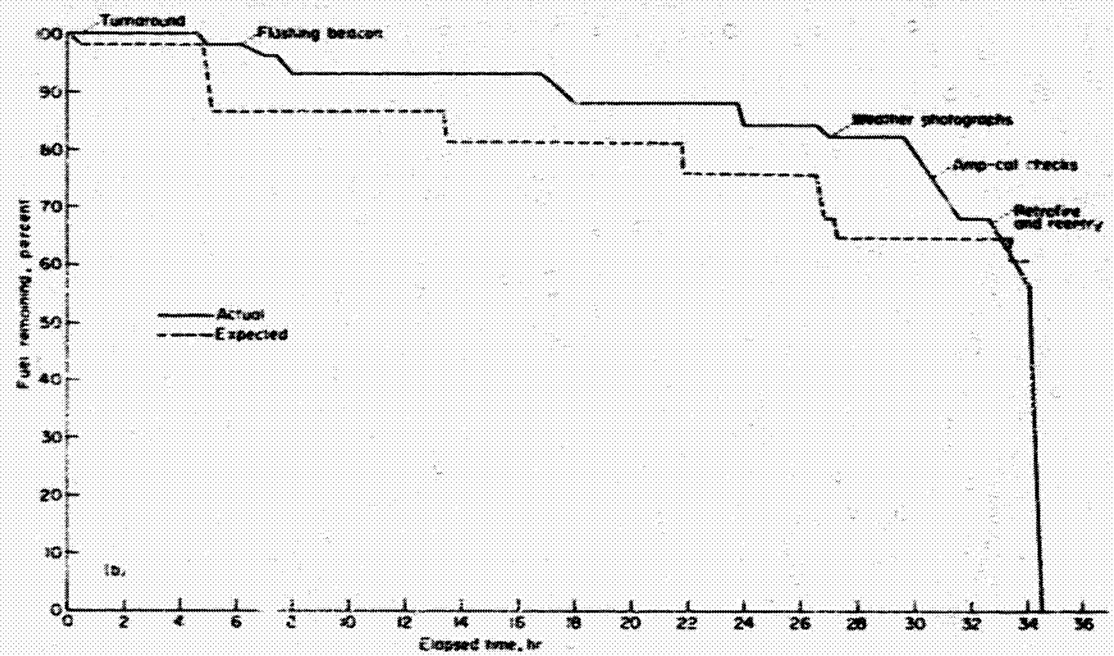
Management of Consumables

An important function of the pilot was to monitor and conserve to the extent possible the various consumables, including attitude-control fuel, electrical power, oxygen, water, and the onboard recorder tape. The first two items were extremely critical to the success of the mission since mismanagement or a malfunction affecting either of these quantities could cause an early mission termination or a loss of the spacecraft.

Attitude-control fuel was the prime consumable quantity over which the pilot had both monitoring and control capability. The normal premission procedure was to establish both predicted and minimum fuel-consumption levels that were expected and required for a successful mission. After lift-off, the management of the control fuel to meet the mission requirements was the sole responsibility of the pilot. It was found that for both the Redstone missions and the first two manned orbital missions the fuel quantities required were within the system capabilities; however, during the later two missions the longer duration required that particular attention be paid to this parameter. In most cases, particularly during MA-9, the pilot demonstrated an ability to perform the required maneuvers by using less than the expected amount of fuel and to stay well below the predicted and minimum fuel consumption levels as illustrated in figures 17-8(a) and 17-8(b).



(a) Automatic system.



(b) Manual system.

FIGURE 17-8.—H_2O_2 fuel usage.

Electrical power capacity was ample for the shorter duration missions, such as the MA-6 and MA-7 flights. However, monitoring of this quantity was still of importance since a malfunction, if major, could jeopardize flight safety. It was only during the final two missions that electrical power conservation became a concern with respect to full completion of the mission. During the last two missions the electrical power source was not sufficient to allow the use of all electrical equipment throughout the mission and still have an adequate reserve. Consequently, the flight plan included periods of drifting flight in order to conserve power. Thus, during both these missions, it was very important that the pilot monitor and control closely this consumable quantity.

Inflight Activities

Flight Plan

The activities of the pilot on each Mercury mission included requests and requirements from medical, engineering, and scientific areas. In order to obtain the maximum amount of information from each mission, it was necessary to schedule all the activities of the pilot and to assign a priority system in the event of overlap between activities.

The type of activities with which the pilot was involved varied from mission to mission, but generally they included normal systems monitoring and control, spacecraft attitude control, systems checkout, air-ground coordination, medical, and experimental. Activities related to mission reliability such as spacecraft control were given top priority. Second priority activities were those investigations which were intended to improve the spacecraft and its mission capabilities in general. Third priority was given to the experimental and other operational activities that were not directly related to the mission safety. Once all of the flight activities had been determined, they were formulated into a flight plan that was designed to meet all of the objectives of the mission.

The period of weightlessness of the manned Mercury-Redstone flights was too short to allow many activities. The flight plan for these two missions concentrated primarily upon the overall operational requirements, and during the weightless period emphasis was placed upon an evaluation of the various spacecraft attitude-control systems. Starting with the MA-6 mission, all conditions during orbital flight had to be considered. The launch, retrofire, and reentry procedures were similar to those of the Mercury-Redstone missions; however, the orbital period required detailed scheduling. Spacecraft systems checkouts were scheduled following insertion and at the end of each orbital pass. Activities related to mission control and mission-orientated information, such as medical, control-display analyses, and experimental activities, were scheduled so that they would not interfere with basic operational tasks. Results of each mission were analyzed and the knowledge gained was applied to the subsequent missions. The following are the general areas where improvements were made based on the previous mission experience. First, pilots were allowed more time for each specific activity. The first orbital pass was reserved for systems checkout, and time was allowed for the pilot to become orientated to his new environment. More time was allotted for monitoring systems, and the air-to-ground communications were improved and simplified so that they would require a minimum of the pilot's time. Second, the spacecraft systems were analyzed in more detail and the pilots were thoroughly briefed on their characteristics. The spacecraft configuration and activity schedule were also finalized at an earlier date than had been true on previous missions and this allowed the pilot valuable additional time to train and become more familiar with the flight activity schedule.

The sum total of all these improvements was reflected in the MA-9 mission plan. At only one period did the pilot feel rushed; however, even in this case he was able to complete the scheduled activity. Two additional factors which contributed greatly to the improved flight activity schedule of the MA-9 mission were that activities were scheduled at any of several different points in the mission so that the pilot could conduct the activity at the most convenient time and that the increased mission duration allowed a reduction in the frequency of activities.

Communications

Air-to-ground communications procedures were continually being improved throughout the Mercury program in an attempt to determine the best set of procedures which would be simple for the pilot and yet insure proper information flow.

The MA–6 pilot was requested to report a large quantity of information to the various ground stations. Over each ground station, he reported the fuel and oxygen quantities, the control mode, and the general status. In addition, approximately twice during each orbital pass, he was required to report to a ground station all the switch positions and gage readings on the instrument panel. In addition many communication attempts were required to establish contact with each station, primarily because the stations would attempt communications contact prior to the expected acquisition time. These premature attempts resulted in many additional transmissions in an attempt to make two-way communications contact.

Several changes were made in communications procedures prior to the MA–7 flight. The requirement for reporting all the switch and gage readings was deleted and the initial transmission from the ground was not begun until the expected time of acquisition. The MA–8 pilot reported only control mode and status. In addition, many intermediate transmissions were eliminated because the pilot transmitted specific information at given stations, which reduced the number of requests initiated from ground stations. The net effect of all these changes was to decrease the amount of the pilot's time required for this activity and thus permit more time for other activities.

The MA–9 communications procedures represented the application of all the previous experience and included several major improvements. Ground stations did not attempt communications with the spacecraft until after they had received the spacecraft telemetry signals and had evaluated the data. This procedure insured that the spacecraft and ground station were in good communications range. In addition the MA–9 pilot reported only go–no-go status to each station and read out fuel and oxygen quantities once per orbital pass. The sleep period, during which communication silence was maintained, also greatly decreased the total air-to-ground communications. One communications problem that did occur during the MA–9 flight was an interruption due to ground station communications while the pilot was conducting the dim-light experiment.

Conclusions

Conclusions concerning the performance of the pilot during the Mercury program and the implications for future manned space programs are:

(1) The pilot during Mercury flights was a reliable and flexible part of the system, and therefore enhanced mission success.

(2) The three-axis hand controller proved to be adequate for spacecraft control.

(3) Although the Mercury training equipment was generally adequate, good external displays would have provided valuable additional training.

(4) Spacecraft systems modifications should be finalized as early as possible to permit earlier flight-plan finalization and to allow more time for the pilot to practice the various inflight tasks.

(5) There was no significant effect upon pilot's operating capabilities resulting from his being subjected to the space environment for up to 34 hours.

(6) Throughout the Mercury Project there was a trend toward design and operational concepts similar to those for flight-test aircraft. This indicates that the decades of aircraft experience will be very useful in designing systems, selecting and training astronauts, and mission planning.

(7) It is advantageous from a reliability and systems simplicity standpoint to make maximum use of the pilot's capabilities in spacecraft operations. Early design should take manual operation into consideration in order to achieve a most effective and efficient overall system. Those functions that are determined to be beyond man's capability or are of a monotonous or repetitious nature should be designed for automatic operations.

References

1. Staffs of NASA, Nat. Inst. Health, and Nat. Acad. Sci.: *Proceedings of a Conference on Results of the First U.S. Manned Suborbital Space Flight.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.), June 6, 1961.
2. Staff of NASA Manned Spacecraft Center: *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
3. Staff of NASA Manned Spacecraft Center: *Results of the First United States Manned Orbital Space Flight, February 20, 1962.* Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
4. Staff of the NASA Manned Spacecraft Center: *Results of the Second United States Manned Orbital Space Flight, May 24, 1962.* NASA SP-6, Supt. Doc., U.S. Government Printing Office (Washington, D.C.).
5. Staff of NASA Manned Spacecraft Center: *Results of the Third United States Manned Orbital Space Flight, October 3, 1962.* NASA SP-12, Supt. Doc., U.S. Government Printing Office (Washington, D.C.), Dec. 1962.